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Hannah Mareike Marczinkowski & Poul Alberg Østergaard

Sustainable Energy Planning, Department of Planning, Aalborg University

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	Date	Person(s)	Organisation
Author(s)	2018-05-27	Hannah Mareike Marczinkowski	AAU Plan
Input from	2018-06/07/08	Poul Alberg Østergaard, Alicia Gutting, Steffen Bettin, Toke Haunstrup Christensen, Jan Jantzen	AAU Plan, ÖAW, AAU SBi, SE
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Abbreviations

CHP	**Combined Heat and Power (plant)**
DH	District Heating
DSM	Demand Side Management
DSR/DR	Demand Response
el	electricity
ESA	Energy System Analysis
EV	Electric Vehicle
HP	Heat Pump
PES	Primary Energy Supply
PP	Power Plant
PV	Photovoltaic (systems)
RES	Renewable Energy Sources
th	Thermal energy
V2G	Vehicle-to-Grid
Wh **kWh** **MWh** **GWh** **TWh**	Watt hour 1000 Wh 1000 kWh 1000 MWh 1000 GWh

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ERA-Net Smart Grids Plus is an initiative of 21 European countries and regions. The vision for Smart Grids in Europe is to create an electric power system that integrates renewable energies and enables flexible consumer and production technologies. This can help to shape an electricity grid with a high security of supply, coupled with low greenhouse gas emissions, at an affordable price. Our aim is to support the development of the technologies, market designs and customer adoptions that are necessary to reach this goal. The initiative is providing a hub for the collaboration of European member-states. It supports the coordination of funding partners, enabling joint funding of RDD projects. Beyond that, ERA-Net SG+ builds up a knowledge community, involving key demo projects and experts from all over Europe, to organize the learning between projects and programs from the local level up to the European level.

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The *Markets, actors, technologies: a comparative study of smart grid solutions* (MATCH) project runs from February 2016 to July 2018 and is supported by ERA-Net Smart Grids Plus.

https://www.match-project.eu

Improving energy efficiency and replacing fossil fuels with renewable energy are among the most important measures on the road to a sustainable energy system. This implies new ways of generating and consuming energy as well as new forms of relations between the energy producers and consumers. The MATCH project contributes to the shift to a carbon-neutral energy system by zooming in on the changing roles of small consumers in the future electricity system (the "smart grids").

The overall objective of MATCH is to expand our knowledge on how to design and implement comprehensive smart grid solutions that take into account the complexity of factors influencing the effectiveness and success of smart grid initiatives targeted at small consumers. The study is cross-disciplinary and based on detailed studies of current smart grid demonstrations in Norway, Austria and Denmark. Through comparative analysis across cases and countries, the study identifies key factors related to technology, market and actor involvement in developing integrated solutions that "work in practice".

MATCH also covers energy system analyses and modelling of scenarios to discuss the wider energy system implications of upscaling the studied cases and solutions. This is addressed in this report.

1 Introduction

This is the deliverable of work package (WP) 4 of MATCH. Its purpose is the presentation of the WP's energy system analyses, which are influenced by the previous work packages and related studies. The main aim is the analyses of the dynamic relations between different smart grid solutions for small consumers to provide recommendations on how to combine and integrate solutions on a system level. The outcome is a number of scenarios that visualize the system-related consequences of combining different solutions.

Specifically, the case studies from WP2 describe various technological solutions in relation to consumer involvement [1]–[3], of which the core characteristics are the focus in WP4. Therefore, the energy system analyses in WP4 investigate the technological aspects rather than the social involvements. However, society and consumer can shape the energy system as much as the technologies which supply it. If demand side management on the consumer side is a result from the demonstration projects, it would influence the energy systems as well.

The scenarios of this WP aim at the evaluation of the various technological solutions from the case studies in Austria, Denmark and Norway. With different energy systems, markets and stakeholders involved in each region, technological solutions might have different impacts on the overall energy systems of the three countries. The resulting comparison can point to strengths and weaknesses of certain technologies, of the combination of technologies with markets or actors, and of regions with different energy systems. Furthermore, it touches on the question if certain combinations work better than others and under which circumstances. Finally, the consequences of upscaling or rescaling the solutions to other contexts are explored and what lessons can be learned. This can lead to interesting conclusions for others studying smart grid approaches.

As part of the MATCH project, the main areas of "markets", "actors" and "technologies" are included to the best extent. While markets influence not only decision-making processes, it can have impacts on the evaluation of technological solutions, such as feasibility and pay-back times. In the energy system analysis, a market perspective can be applied to evaluate this further. The actors, on the other hand, do not have a direct influence on the analysis, but are rather part of the decision process, which leads to the choice and implementation of technologies. As pointed out in the first Deliverable of MATCH [4], technology is *an integral element of society, which means that we cannot analyze society without a view to technology*. Finally, the technologies form the main area of this WP and are evaluated in various scopes and several scenarios. This is done with the energy system simulation tool EnergyPLAN, which evaluates them in regards to technical and environmental feasibility.

The last part enables a process-oriented view on smart energy system solutions. As practices and technologies are introduced and changed constantly, a thorough simulation of scenarios can adapt to this. It, furthermore, shows how solutions can work from a technical view, excluding the influences from markets and actors, such as business and personal views. While the technologies' role, interpretation, understanding and consequences are evaluated in WP2 and 3, this WP4 aims to include the impacts for the energy systems. The technological approaches from MATCH that are focused on and can be analyzed are:

- Demand side management and demand response solutions (for demand reductions or shifts)
- Micro-generation (on consumer side)
- Storage technologies

The tool for creating the scenarios around these approaches is defined and explained in Chapter 2. Here it becomes clear to which extent the interaction and acceptance of technologies with the social and the market level influence the analysis or not. The three approaches are further discussed in Chapter 3 in relation to the outcomes from the case studies as well as in relation to the further analysis. The result is presented in Chapter 4 with three main energy system analyses (ESA 1-3), after which Chapter 5 sums the report up with a discussion and conclusion.

2 Modelling tool

This chapter presents the approach to the energy system analysis in general and in the specific case for the MATCH project. Therefore, general steps, characteristics of the energy systems simulation tool and the connection to the components of the MATCH study cases are presented.

An energy system analysis aims at the investigation and evaluation of factors or technologies that aim at improving a part of the energy system, while simultaneously influencing the whole system. The impacts of smart grid solutions for instance, not only affect the electricity sector but also the heating sector and the transport sector, thus these are also to be analyzed from a holistic energy systems approach. Energy systems with a strong integration between sectors may be denoted smart energy systems.

In a smart energy system there is a focus on the exploitation of synergies in the energy system to ensure high efficiency and feasibility. They additionally aim at 100% renewable systems - including a sustainable use of bioenergy. A sole focus on the electricity sector (as with a smart grid) is advised against as it could lead to the requirement of expensive storages and flexible demand solutions instead of integrating the electricity sector as part of the smart energy system, where electricity surplus and deficits can be managed through heating, industry, gas and transport technologies.[5]

The operation of a (smart) energy system can be simulated with EnergyPLAN [5]. EnergyPLAN includes demands in the electricity, heating, cooling, industry and transport sectors, production and storage technologies, and technologies integrating different sectors. It performs the simulations of the energy system on an hourly basis. Being in line with MATCH's aim of *improving energy efficiency and replacing fossil fuels*, EnergyPLAN is designed to coordinate the various demands with the utilization of renewable energy and conversion technologies with the potential to replace fossil fuels or improve efficiencies in the system. *"Consequently, the EnergyPLAN tool can be used for analyses which illustrate, e.g., why electricity smart grids should be seen as part of overall smart energy systems"* [6]. In the MATCH project frame, this includes smart-grid technologies, such as demand side management solutions, micro-generation and storages.

The main focus of WP4 can be summarized as the analysis of the dynamic relations of smart grid solutions for consumers by investigating and showing how to combine and integrate solutions on a system level. The outcome is scenarios that visualize system-related consequences of different solutions. Using EnergyPLAN, the energy system(s) can be modelled in a simplified way, with the possibility of comparing different regulation strategies, as well as abilities to integrate and trade RES.

However, EnergyPLAN also has characteristics, which might limit the possibilities for the energy system analysis in the MATCH scope. It operates on a holistic level, encompassing all sectors and focuses on connections between the different energy sectors with some level of aggregation. The MATCH case studies, on the other hand, primarily focus on single constellations of technological solutions with some level of detail. This WP goes beyond the sociological perspective of previous WPs by adding the system perspective. It models energy supply and demand on an aggregated level, representing various production and demand units of a particular technology typically by one unit, while not investigating all single units individually. Here, the up-scaling of the various approaches becomes important.

Furthermore, the scope of analyses in EnergyPLAN varies typically from small town to national models, excluding smaller system set-ups like single buildings. Specifically, EnergyPLAN works well for municipalities and cities that have various interrelations of sectors. This is done on an hourly basis for a full reference year, taking into account seasonal and daily variations, which enables detailed studies. For the MATCH analysis, national models are therefore analyzed with up-scaled versions of the various small approaches that proved successful in the case studies.

Finally, the energy system simulations in EnergyPLAN can be done in a technical or economic optimization approach. Usually, the technical simulation is chosen when focusing on energy balances, CO_2 emissions and excess electricity production, or when focusing on the technical possibilities of future energy systems. Alternatively, a market exchange simulation focuses on the economically optimal exchange strategies where dispatchable units are operated on an external electricity market. With MATCH emphasizing energy efficiency and replacing fossil fuels in future energy systems, the technical simulation is chosen.

An overview of energy sector relations that EnergyPLAN can simulate is shown in the energy system overview in Figure 2.1. While some of the units presented are only used in specific cases, the supply and demand of electricity, heat and transport present the basic energy system cornerstones. Additionally, the technological approaches suggested in MATCH can be addressed through the drop-down menu of the different tabs on the left, as illustrated in the same figure.

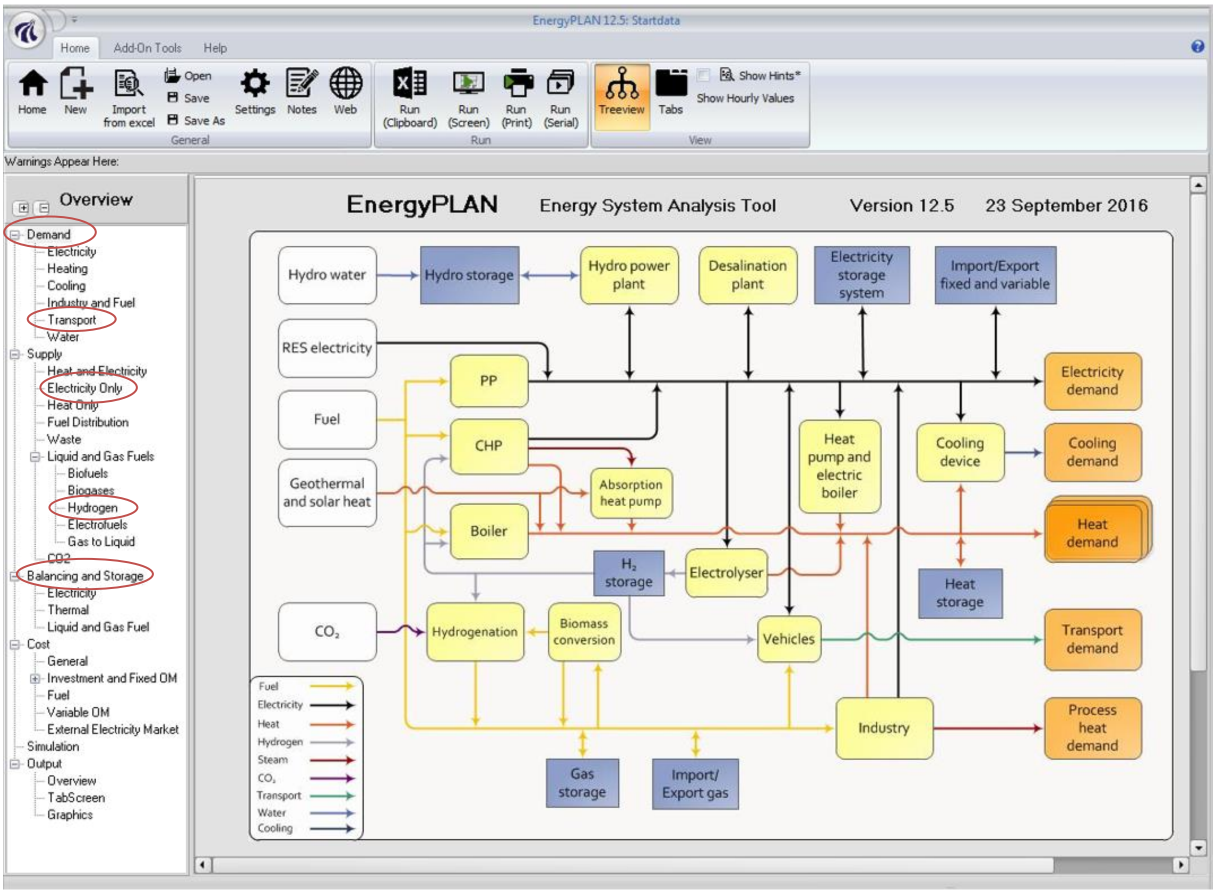

Figure 2.1: Energy system overview in EnergyPLAN and MATCH approaches possible to analyse

Concluding from the previous WPs, new components that are part of the MATCH project include changes in the demand (DSM), changes in the transport demand through additional Electric Vehicles (EV), supplying electricity with Photovoltaics (PV) through micro-generation, hydrogen as alternative fuel as well as storage solutions, both electric and thermal. Their variation, interaction and dependencies can be tested and evaluated in the system through EnergyPLAN.

The MATCH solutions can be tested and analysed by adjustments of the corresponding energy supplying units or demand profiles. Demand side management and response solutions for demand reductions or shifts can be analysed by defining the hourly demand profiles, which EnergyPLAN employs to model demand and seeks to furnish the supply to. Lower demands in general or in the peak hours would result in lower fuel demands and emissions for the energy system supply. As transportation is part of demand, an increase in EVs could simultaneously lead to less fossil-driven cars. Micro-generation, for example PV systems, can be added in the electricity supply section in EnergyPLAN. The additional approach of hydrogen addition to an energy system, as it is addressed in the case study of a Norwegian wholesaler, is a further conversion and supply technology. The final MATCH approach of storage technologies is addressed in the balancing tab, where electric battery systems are classified with capacity and discharge/charge powers. However, these are modelled to balance the total energy system, not individual users privately. The focus areas from the previous MATCH investigation are explained in more detail in the following.

3 Focus areas/shaping modelling approaches

In the following, the three general main technological approaches are discussed in greater detail. Afterwards, the study cases are related to the individual approaches to give an overview of what is applied where. Based on that, the outline and approach of the energy system analysis is presented.

The first approach is **demand side management and demand response** (DSM/DR), which addresses the demand side of the energy system: the customer or consumer. The idea is that with various metering and feedback technologies, awareness is raised on the consumers' side, leading to possibly altered practices or reduced energy usages. This can be supported by remote control of cooling/heating devices in relation to the current markets or simply by education of the consumers.

A good example is the approach the Samsø Energy Academy took with shops and businesses, analyzing possible energy efficiency measures and options for demand management. Next to others, consumption was suggested to be shifted to off-peak hours for a small dairy farm. Energy saving actions were proposed for off peak hours in shops and supermarkets, for example nightly temperature setback. Similarly, ProjectZero in Sønderborg, Denmark, addresses shops, public facilities and other buildings with efficiency measures, such as efficient light bulbs or natural ventilation supporting the heating and cooling demands. In addition, PVs in combination with EVs and/or heat pumps (HP) in households was investigated. In the case of the island of Fur, Denmark, households invested in PVs, which are categorized as micro-generation, in combination with batteries, which are storage technologies. The result is an alteration of the demand side through monitoring and response of local production and consumption, connected to changing their own consumption patterns. This shows how some of the MATCH approaches are closely related and might not be able to be analysed separately. [2]

Similarly, the involvement of the consumer in the demand side management was addressed in the Austrian and Norwegian cases, which often led to improvements [1], [3]. However, no concrete results were documented on what these approaches would look like in a larger scale or a longer timeframe. For an energy system analysis, the management and response on the demand side can therefore best be analyzed with a changed demand profile in the EnergyPLAN models. As discussed, the integration of PV and EV can be considered a contribution to DSM, which is both strongly represented in Austria and Norway.

The second general approach is the **micro generation** in relation to create and support a smart grid as part of a smart energy system. Most commonly, the investment in PV panels is considered within the MATCH study cases, but also a small combined heat and power plant (CHP) in the Rosa Zukunft project in Salzburg, Austria, and a hydrogen production facility in Norway are included. This can be evaluated with the energy system analysis, as the production and supply of other energy types, such as electricity from power plants (PP) or fuel for transport, can be influenced.

PV panels, on the other hand, influence not only the consumers' demand from the grid (DSM, DSR) but also feed into the grid when the electricity production exceeds the local demands. Micro generation with PV is focused in most of the study cases as Table 3.1 shows. Some exceptions are Rosa Zukunft and some of the approaches on Samsø and in Sønderborg, as they do not directly focus on this topic, but DSM as explained above.

The final approach refers to all the **storage** possibilities that were investigated in the MATCH study cases. These vary from battery electricity storages to heat and hydrogen storages. Some studies also consider the batteries of EVs as storage options, where EV batteries are also used for electricity supply (vehicle to grid (V2G)). In Vorarlberg, some stationary electricity batteries were made out of old EV batteries, while the other listed batteries in Table 3.1 are common residential batteries of typical sizes for households, often in connection to PV systems. Heat storage is only applied at the Rosa Zukunft project in combination with CHP and HP, and hydrogen storage results from the local hydrogen production from the Norwegian wholesaler Asko, making them both very specific storage solutions.

Table 3.1: Variation of MATCH approaches in study cases

		DSM/DSR	Micro generation	Storage technologies
Austria [1]	Köstendorf (Salzburg)	Smart meters, DSR	PV	EV/Battery
	HiT Rosa Zukunft (Salzburg)	DSR, Energy efficiency, HP	CHP, PV	Heat storage
	Vorarlberg (VLOTTE)	/	PV	EV/Battery
Denmark [2]	Fur	Smart meters	PV	Battery
	Samsø (NightHawks)	Smart meters, Energy efficiency	/	/
	Sønderborg (ProjectZero)	Energy efficiency	PV	EV
Norway [3]	Trøndelag (Demo Steinkjer)	Smart meters	PV	/
	Hvaler	Smart meters, DSM	PV	EV
	Asko wholesaler Midt Norge	/	PV, Hydrogen	Hydrogen storage

All three solution areas include proven technologies to some extent, but in various scales and scopes. In order to make energy system analyses, the relation to the specific study cases as presented in Table 3.1 is not directly utilized, but general findings are chosen and evaluated for three different regional areas: an Austrian, a Danish and a Norwegian case. For these national cases, successful solutions are modelled as they were applicable in the respective countries of the case study, but successful solutions of one country are furthermore analyzed for other countries as well to see their replicability in other frameworks. More details on this follows in the next section.

3.1 Areas of investigation

The individual investigations of the different approaches take their point of departure in the most successful or most common study cases for each of the studied countries. While these are analyzed on the national scale, the second step is the investigation of its success in different national context. Table 3.2 illustrates the idea, where the various national cases are formed into three approaches to be adapted to the whole country and afterwards to the two other countries.

Table 3.2: MATCH approaches to be analyzed

<table>
<tr><td></td><td colspan="3">DSM/DR - Micro-generation – Storage technologies</td></tr>
<tr><td>Austria reference model</td><td rowspan="3">Austrian approach (Applied micro-generation and storage: CHP; HP; PV, heat storage)
↓</td><td rowspan="3">↑
Danish approach (Applied DSM/DR and micro-generation: PV, tariffs, energy efficiency → demand shift)
↓</td><td rowspan="3">↑
Norwegian approach (Applied DSM and storage: EV)</td></tr>
<tr><td>Denmark reference model</td></tr>
<tr><td>Norway reference model</td></tr>
</table>

As described before, PV is often a complimentary technology in addition to other solutions in the case studies. Since it is furthermore a rather well known technology with a predictable outcome, it is not further included in all of the approaches. Only the Austrian case includes actual PV capacity increases.

The Austrian case – to be known as Energy System Analysis (ESA) 1 – reflects the idea of the Rosa Zukunft study case with a focus on its (micro-) generation and storage qualities. For this case, the heating sector is also addressed next to the electricity sector. This is due to the considered increase in the district heating (DH) share by implementing CHP and HP on a larger scale. While Rosa Zukunft's idea is about micro-CHP and building-size solutions, the ESA1 scales this up to a national scale, resulting in using the general term DH, even though Rosa Zukunft technically is not. To evaluate the feasibility of the HP, an additional PV capacity is added. Whether having several micro-CHP or a few large CHP will give the same results in EnergyPLAN due to its aggregation, as explained in Chapter 2. [7]

The Danish approach (ESA2) focuses on the DSM and DR ideas, which are strongly represented in the Danish cases, but in general all countries know about its importance and therefore, a widely known approach is considered in the second approach: time shifts in the electricity consumption. This is also partly discussed with possible dynamic/variable electricity tariffs and with the aim of peak shaving. While PVs are not added in this analysis, the effect of PVs making homeowners shift their demands is indirectly represented, by reducing some of the demands, which would have otherwise occurred in the evening hours.

The third ESA approach evolves from the Norwegian trend of increased EV usage affecting their energy system [8], but also from an increased focus in other countries and in various constellations, such as private, public or commercial transportation. With EVs playing a minor role also in other countries, the implications of this technology, also as a possible storage option, becomes interesting to study in the various national contexts.

All three approaches can also be recognized in the other study countries to various extents. For example, the case study of Hvaler, Norway, includes not only the plans to roll out a high number of charging stations for EVs, but also the introduction of power tariffs, which resembles the "Danish" approach [3]. In addition, EVs have played an important role in Austrian case studies and appeared in studied areas in Denmark as well. Electrifying the transport sector is thereby addressed through ESA3.

Table 3.3 presents the idea of the various energy system analyses (ESAs) and their relations to the core MATCH points: Markets, actors, technologies; specifically DSM, microgeneration and storage. Each of the ESAs presents a different combination of MATCH's focus areas and targeted technologies.

Table 3.3: Overview of energy system analyses regarding focus areas and technologies

	Markets	Actors	Technologies:	DSM	Micro generation	Storage
ESA1	Heat and electricity (prices)	-	CHP, HP, PV	-	PV (CHP, HP)	Heat storage
ESA2	Electricity	Interaction partly required 5-10%	(only indirect)	Peak shifts (based on PV, tariffs, "efficiency")	-	-
ESA3	Electricity	EV owners	EVs, Smart Charger, V2G	EV charging hours	-	V2G

To investigate these approaches, the national reference models are adjusted and comparisons of the three energy system analyses with the reference are made. The evaluation concentrates on the impacts on changed fuel consumption, CO_2 emissions, import and export balance. The questions that will be answered are:

How do the case studies work in different energy systems? What do they do to the rest of the energy system? Where does what work best or worse and why?

4 MATCH approaches on a national scale

Based on the before-mentioned successful approaches from the various study cases in Austria, Denmark and Norway [1]–[3], as well as the limits presented, this chapter focuses on the resulting energy system analysis of the three countries.

For comparability with the existing national energy systems and to model both close to reality, the models are based on reference scenarios from 2015. These function as baseline models, to which the MATCH approaches are applied and analyzed. The application of the national models of Austria, Denmark and Norway enables a thorough investigation of the approaches through the different national energy system layouts.

Each represents a different energy system layout. Denmark has a lot of CHP, wind turbines and DH; Norway has a lot of hydro power, though its flexibility relies to a large extent on seasonal demands and precipitation, and a large share of electrified heating; Austria is also well-equipped with hydro, but also conventional power plants (PP), and has a more dense population than the other two countries. The main characteristics are presented in the following section.

4.1 Reference energy systems

While some things do not influence the MATCH analysis, they nonetheless play a role in the set-up of the energy system and explain not only the current system but also the possibilities for future energy systems. While an energy system is made up of more than the electricity sector, as explained in Chapter 2, the following addresses mainly that sector as well as the heating sector as MATCH operates mainly within these. The complete systems' details of the fuels consumed and capacities available are found in Table 4.1.

With the largest population of the three study countries with 8.8 million inhabitants, Austria's electricity production is only the second highest with 66 TWh, but the largest heat production of 73 TWh. The DH share in the reference model is 29% and the renewable energy contribution to the primary energy supply (PES) is just below 21%, while the electricity sector is supplied with 54% RES.

Denmark represents the medium country in terms of population (5.7 million), but the lowest in electricity and heat production: 37 and 56 TWh respectively. The comparably highest share of 47% of heat supplied through DH is connected with a large CHP capacity. The RES share of the PES reaches above 31%, which increases to 42% RES for the electricity supply.

Norway is the largest of these three countries, but with the smallest population of 5.3 million people. The high electricity consumption is closely related to the heating sector, as Norwegians use a lot of electric heating, which again is comparably high due to the colder temperatures. Therefore, the total electricity production in Norway is 141 TWh and heat production is 60 TWh. The DH share is a modest 9% in the reference model and the renewable share of PES is about 29% due to large hydro power capacities. Electricity-wise, Norway produces more renewable energy than it consumes itself (108%).

Figure 4.1 and Figure 4.2 illustrate the electricity and heat supply for Austria, Denmark and Norway in a comparable way, pointing out the large contribution of hydro power in Austria and especially Norway, as well as the other supplying units and fuels. Regarding the heat supply, Figure 4.2 presents the share of DH in comparison to individually (indv.) heated buildings and the respective fuels or technologies.

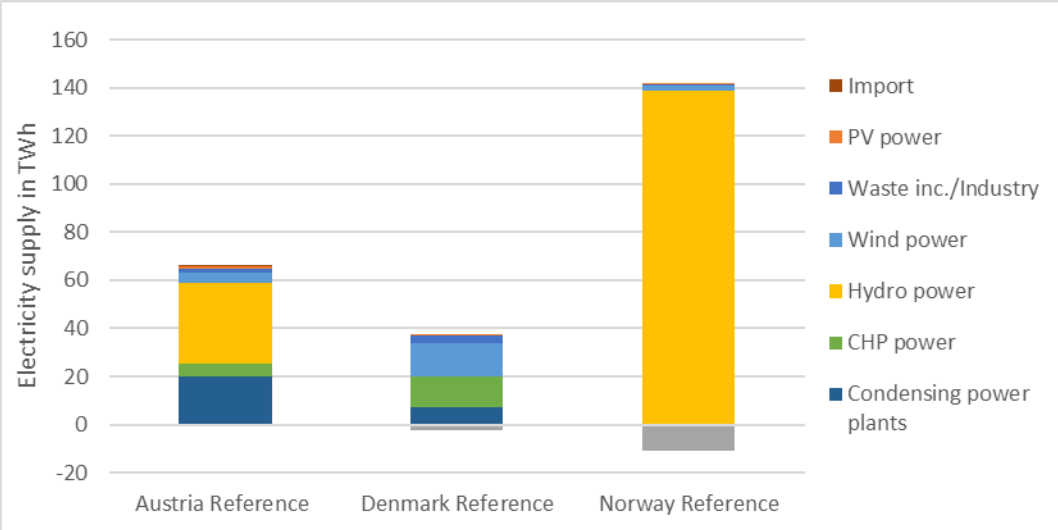

Figure 4.1: Electricity supply by type and country

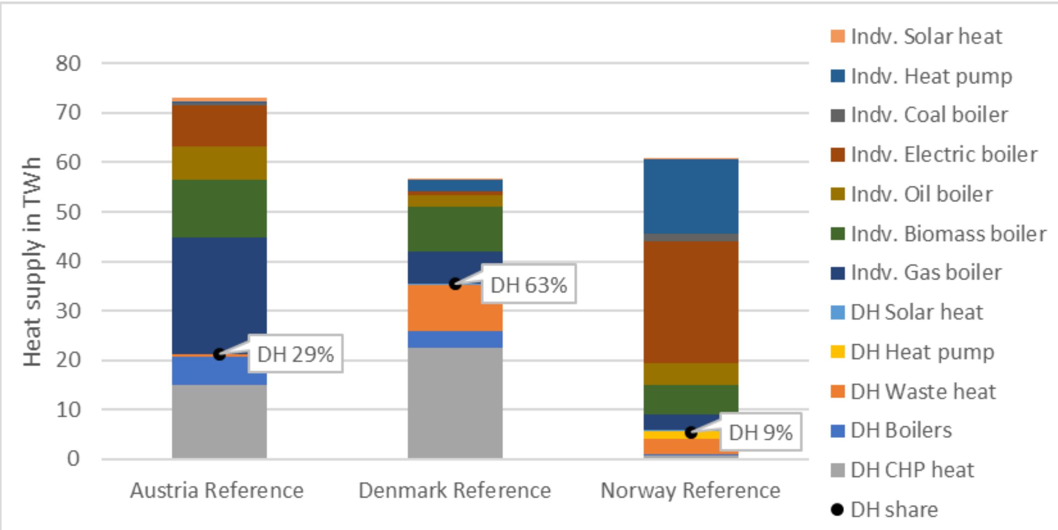

Figure 4.2: Heat supply by type, incl. DH shares, and country

Besides the RES, the power production in Austria is mainly supplied via natural gas, then coal, namely 53% natural gas and 44% coal in in condensing PPs and 44% natural gas and 47% coal in CHP plants. In Denmark, biomass also plays an important role. Next to 63% coal used in the condensing PPs and 57% coal in CHP, biomass is used with 28% and 30% in PPs and CHP respectively. In Norway, the power production from PPs plays generally a minor role, see Figure 4.1, and the also small CHP units are supplied 100% with natural gas. Some details of the three reference systems can be seen in Table 4.1. More details on the energy systems, including various production units and fuel consumption, can be found in the Appendix.

Table 4.1: Overview of national reference models of Austria, Denmark and Norway

Annual modelled values	Austria 2015 reference scenario[1]	Denmark 2015 reference scenario	Norway 2015 reference scenario[2]
Inhabitants in million	8.8	5.7	5.3
Interconnection capacity in MW	12650	6005	8895
Electricity Import/Export in TWh	0.01/0.02	0/2.6	0/10.8
Electricity production in TWh	65.7	37.5	141.2
Heat production in TWh	73.1	56.4	60.1
DH share	29%	63%	9%
PP capacity in MW_{el}	8350	5617	0
CHP in MW_{el} CHP in MW_{th}	1093 2925	4801 8704	100 275
Total DH boiler capacity in MW_{th}	12017	12463	624
Wind capacity in MW	2143	5836	867
Hydro Power capacity in MW	10323	7	31372
PV capacity in MW	797	780	14
Total RES production in TWh_{el}	38.4	14.8	140.6
Coal consumption in TWh	50.9	28.8	16.3
Oil consumption in TWh	119.3	77.3	278.7
NGas consumption in TWh	100.8	36.5	89.5
Biomass consumption in TWh	30.6	50.2	14.1
RES share of PES	20.5%	31.4%	28.7%
RES share of electricity demand	53.9%	42.3%	107.7%
CO_2 emissions in Mt	70.0	39.3	98.3

[1] Denmark and Austria Model by Various, HRE4, Aalborg University [9]

[2] Norway Model by K. Askeland and K. Bozhkova, AAU Master thesis, Aalborg University [10]

4.2 Energy system analyses

As presented in Chapter 3, three approaches are investigated covering the various MATCH ideas, study cases and beyond. Table 3.3 gives an overview over this. This chapter analyses how these ideas are implemented in the reference systems of Austria, Denmark and Norway presented above. The impacts in each of the countries are presented and compared, while Chapter 5 will give a final discussion and conclusion of the analyses.

4.2.1 ESA 1 – CHP and/or HP replacing individual heating with PV support

The technological choice of increased CHP and HP capacity addresses not only the heat supply, but also the electricity supply due to the dependency on the electricity market and prices. The idea results from the Rosa Zukunft study case in Salzburg, Austria [7] and is slightly modified to fit into the first ESA. While Rosa Zukunft focusses on micro-CHP and a building-size solution with various living units in the building, the upscaling of this approach leads to the investigation of DH being the main idea, being supplied with CHP and HP with the support of PV. In terms of aggregated system modelling using EnergyPLAN, there are no differences between modelling multiple micro-scale system or fewer small-to-medium-scale systems.

The main idea is on the one hand to lessen dependency on import from other power or heat producing facilities or countries by increasing self-sufficiency with local and renewable resources. At the same time, CHP and HP are energy efficient technologies that in e.g. Denmark already play an important role in the transition to a sustainable energy system.

Electricity production from CHP can replace production on condensing mode power plants (PP) and replace or support boilers and other heating technologies, depending on the demands of electricity and heat. For this purpose, the heat should be supplied through DH, therefore, this is simulated in the ESA1. For Austria – and afterwards also for Denmark and Norway – 10% of the individual heat supply is upgraded to DH, targeting the individual oil and gas boilers. The corresponding capacities of CHP and HP are aligned with the peak demands for these additional 10% by studying the annual and hourly demand profiles.

Regarding MATCH, this approach addresses markets and technologies, namely (micro-) production and storage. The PV panels are considered to supply electricity for the HPs, which otherwise buy electricity when it is cheap / use electricity when appropriate from a systems perspective. Alternatively, heat can also be supplied through CHP. The PV production and electricity prices, therefore, influence if electricity should be sold, bought or produced. However, PV production is known to be in an opposing cycle to the heating season, so even if the PV capacity is increased by 25%, the question remains about its suitability in this set-up of increased electricity demand for the HPs.

Ideally, this double-investment (CHP and HP) might be cheaper due to this resulting flexibility, but how does it look from the system's perspective in a technical analysis? In EnergyPLAN, the simulation primarily uses renewable energy sources and secondly technologies according to fuel efficiency, meaning where the least fuel would be required. Finally, the electricity prices are not relevant from the technical simulation's perspective. However, the utilization of the CHP (and likewise the HP) depends therefore strongly on the local energy system, specifically available RES, existing CHP capacity and PP characteristics.

Due to the currently existing fuel supplies for PP/CHP, the resulting DH supply will be covered differently in each country as the same fuel shares are applied as used in te reference models. Adding a marginal contribution of extra CHP in a system means that even if the new capacity is higher or more efficient, due to the aggregation, these effects will not be visible in the EnergyPLAN simulations. At the same time, when the HP relies on electricity, the existing market conditions influence and are influenced by its operation. While Austria currently relies by 46% on fossil fuel for its electricity supply, Denmark's electricity demand is covered by 58% by fossils still and Norway produces more renewable electricity than it can use (108%).

Concluding, the analysis addresses an increase of PV capacity of 25% and a transition of 10% individual (fossil-based) heating to DH based on CHP and large-scale HP. For comparison reason, the CHP is afterwards removed to see the result if the focus was on PV and HP alone, as this would cause the HP to increase its operation and give further information about the capability to increase HP vs. CHP.

Figure 4.3 presents the CO_2 emission, the electricity and the heat supply by technology for the mentioned CHP/HP scenarios in comparison to the reference systems for each of the three studied countries. The details can be found in the Appendix with all the results, while the highlights are as follows:

CO_2 reductions always max 1.35% (if DH would be biomass or RES electricity-based, this could be better)
HP operation very different in each country (see graph)

Austria

- DH share increased from 29 to 36%
- With both CHP and HP
  - heat production mainly on CHP (5 TWh compared to 0.2 TWh)
  - fuel consumption and CO_2 emission lowest
  - Reduces power production from condensing PP
  - Exports more electricity, import 0
- With only HP
  - Coal increases due to higher electricity demand, import required
  - Indv. Heating fuels similar to fuel demand for HPs (almost no CO_2 reduction)
- There is a demand for CHP or better electricity supply for HP

Denmark

- DH share increased from 63 to 67%
- Both CHP and HP
  - HP-based heat production increases more than CHP (+1 TWh from CHP and +2 TWh from HP)
  - More CHP enables more RES integration (flexibility), less export
  - CHP reduces electricity from PP and heat from boilers
  - Lowest CO_2 emissions
- Only HP
  - increases electricity demand, which is provided with (existing) CHP and the additional DH demand can be partly covered with existing CHP and the new HP (+0.8 TWh from CHP and +2.1 TWh from HP)
  - Also reduces export to same extent
- electrification to a certain extent good, but DH increase can also be covered with existing technology

Norway

- DH share increased from 9 to 18%
- CHP/HP both utilized (+3.4 TWh, +1.8 TWh)
  - The additional electricity from CHP is mostly exported (export +20%)
  - Boiler and storage use minimized
- Only HP
  - reduces export (-10%) and increases heat production from existing CHP slightly (0.05 TWh), rest covered by HP
- CHP can be implemented, but HP can be better regulated with the existing hydro power

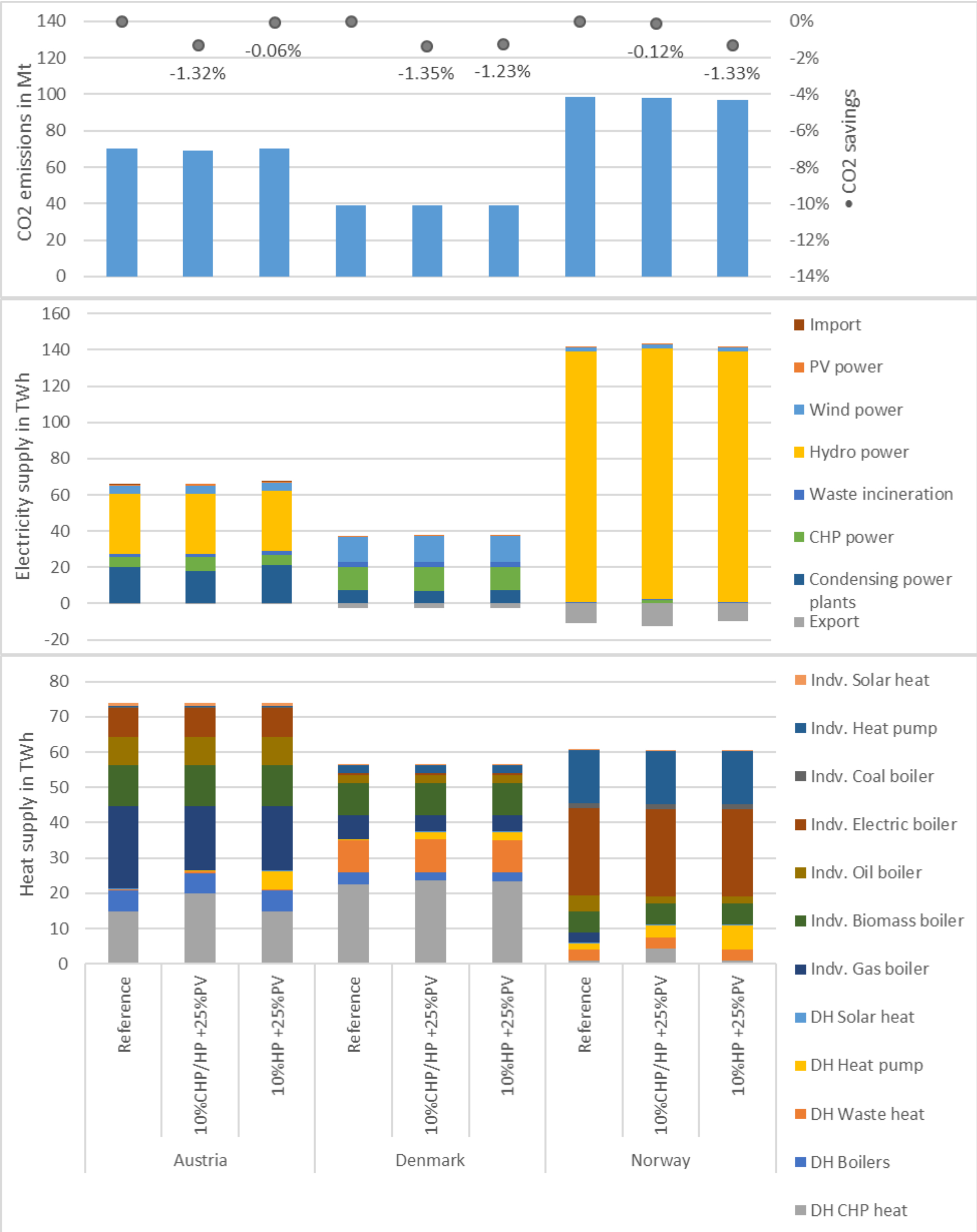

Figure 4.3: Electricity and heat supply by technology for DH scenarios, incl. CO_2 emissions

4.2.2 ESA 2 – Electricity demand time shift based on DSM

As described in Chapter 3, the idea of addressing energy issues through DSM and DSR is a widespread idea, which can take its point of departure in various ways. DSM often refers to improving the management of both electricity and heat demands, addressing the high periods of demands or the general idea of demand reduction through energy efficiency.

While leaving the general reduction of demands aside, the peak demands are preferably approached as they often relate to back-up units to provide electricity and heat in the short term under fuel-intense processes. Peak demands are often (thought to be) in evening hours after work due to routines involving household appliances, such as cooking, washing and entertainment. All three countries typically have the highest values in four-hour blocks, e.g. 17:00-21:00 (20:59), when looking at the hourly profiles of a few days in the beginning of the year in the reference models of the selected countries. For this, see Figure 4.4, specifically for the January graphs.

Some of the peak shaving can be addressed through generally efficiency (reduction) measures or – more specifically – batteries in combination with PVs or price tariffs addressing these potentially problematic hours. This approach therefore represents the ideas and discussion of representatives of the study cases of Sønderborg, the idea behind Fur or the ideas from Halden, where higher prices in peak hours should encourage the consumers to reduce the energy demand in these periods [2], [3]. No matter what the reason behind the DSM, this ESA2 tries to solve the question if a "simple" DSM measure such as this shift is suitable in every context.

Now, the peak is not always at the same time on the different weekdays and in different seasons, but would the tariffs adjust every day or stay fixed? Can the consumer be expected to always stay up to date to the current peak tariffs? Experience from Rosa Zukunft show that residents are not overly content and a negative response can be assumed, therefore, the DSM approach of addressing 17-21:00 is assumed fixed here (so-called static time-of-use pricing), as it makes most sense for consumer acceptance, understanding and regulation.

In an optimal case, the reduction on the residential side can reach magnitudes of 10-30%, depending on the energy system and the shares of other consumers. This leads to an average of 5% of these peaks to be reduced (of the total national electricity demand, incl. residential, commercial and industrial demands, but excl. transport, heating, cooling). This reduction can entail processes, such as dishwashing, laundry or car battery charging to be moved to the night hours 23:00-6:59.

Figure 4.4 shows the 48-hour spans of two days in January and in July for the studied countries, where this approach is analyzed. In January, the peaks are in the evening hours, as mentioned above, but also partly around noon as a typical increase in demands due to lunch preparations. In the summer, such as July, peaks are actually in the morning/noon, partly because the winter demands for lightning and heating are reduced and because of the increase in consumption in the morning from starting and increasing daily operations at work and at home.

The dashed lines in the figure present the possible impact the tariffs from 17-21.00 could have. With different total electricity demands, also the 5% shares vary, as can be seen in the magnitude of Norway's DSM approach. As can be expected from this graph, the "simple" DSM might not have solely positive impacts as the summer peaks are (mostly) missed with this approach – so does it still make sense to move demands to the night? How does the energy system react to this idea?

Next to the 5% approach, a sensitivity study of 10% is added to clarify and amplify the impacts such actions could have. While the details of this analysis can be found in the Appendix, Figure 4.5 presents the two approaches in comparison with the reference energy systems.

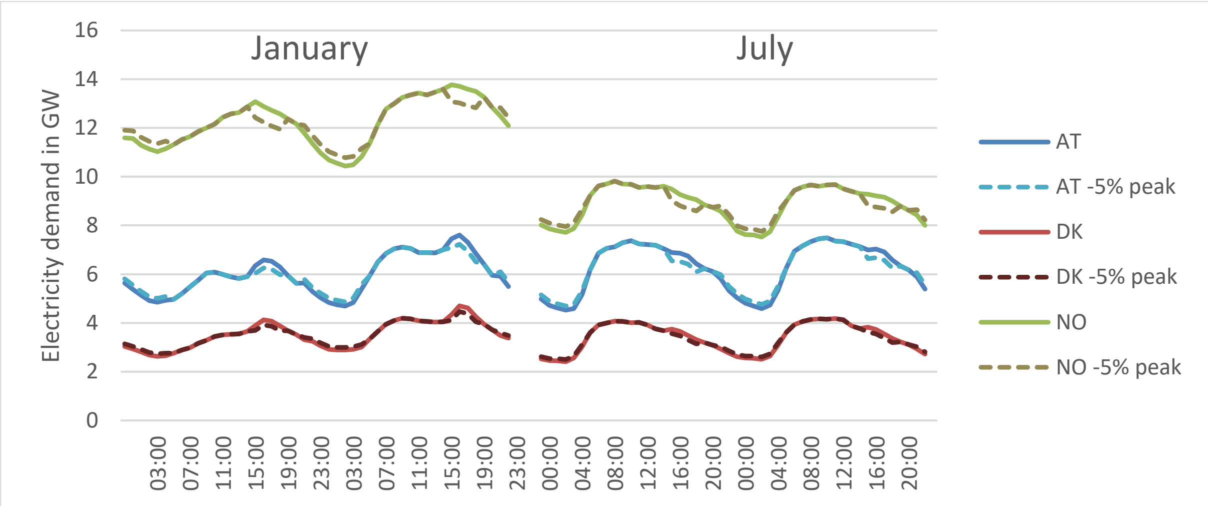

Figure 4.4: DSM approach illustrated by electricity demand profiles for 48 hours in winter/summer before and after peak shift

The highlights of the results (referring to 10%, even though that is not the realistic case, but points to general trend and insignificant changes in the 5%-shift):

Austria

- CO_2 reductions by 47 kt/year (-0.07%)
- Decreases fuel consumption by 210 GWh
- More hydro power can be used
- Export decreases
- PPs need to run less
- Instead, CHP run more and also provide a little more heat, so less heat from boilers

Denmark

- CO_2 reductions by 48 kt/year (-0.12%)
- Fuel consumption -190 GWh
- Less CHP, less PP
- Less export
- Reduced CHP operation = more heat from boilers

Norway

- CO_2 reductions by 10 kt/year (+0.01%)
- More CHP, because Hydro is prioritized to supply the electricity demand (heat can also be supplied with CHP; HP is reduced)
- Hydro modelling is limited by the fixed storages at end/beginning of the year (same level)
- Compared to the reference, the shift reduction increases the electricity demand at hours, when there is also high heat demand (conflict of hydro supporting electricity and heating demand)
- More fuel +30 GWh (+0.01%) due to increased CHP operation

With alternative demand profiles, this could change easily (both alternative reference and new profiles, e.g. DK profile results in less conflict)

In Figure 4.5, it can be noticed that the CO_2 reduction is not as significant as in ESA1. Furthermore, the heat supply graph presents only the DH supply, as the individual heating is not affected.

While Figure 4.5 indicates only minor implications of this approach, the details in the tables in the Appendix show small improvements for each of the countries, incl. reduced fuel consumption in Austria and Denmark, while the demand shift is not as flexible in Norway.

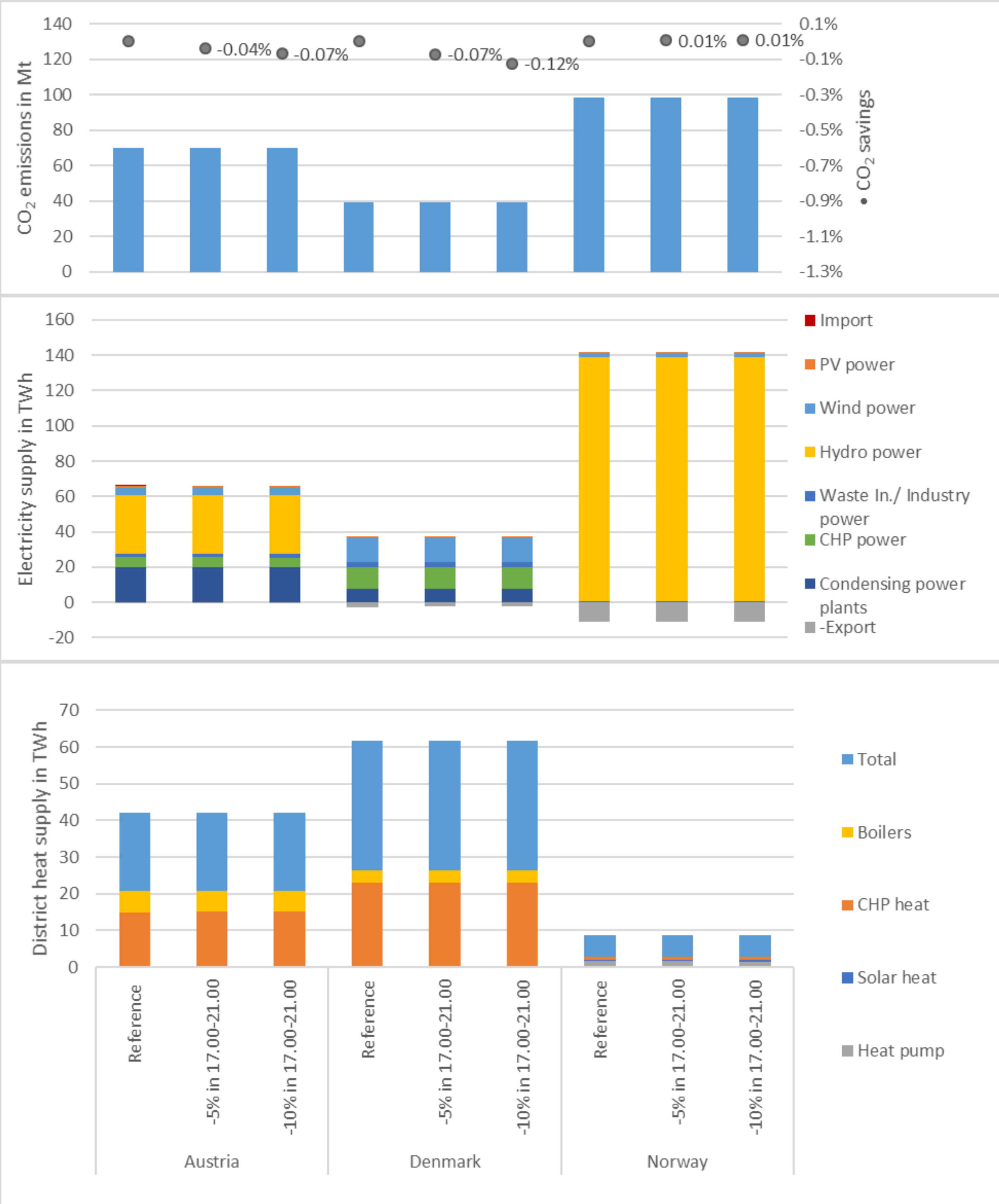

Figure 4.5: Electricity and DH supply by technology for DSM scenarios, incl. CO_2 emissions

4.2.3 ESA 3 – EVs and charging variations: dump/smart/V2G

After the micro-generation with heat storage and the DSM focus through peak shifts in Sections 4.2.1 and 4.2.2, this section is focusing on EVs as a contribution to the demand side through increased electricity consumption, but also as a possible contribution to electricity storage through the V2G option. While several of the study cases investigate EVs, batteries and charging options, the Norwegian situation has the most influence on ESA3. [8]

EVs are a technology with possibly high impacts and interactions with the systems, markets and the consumers. Depending how the trend develops, its growth can have large implications on the energy system, depending on its configuration, but even more so on the way the technology is integrated. Not only do the charging option and owner habits matter, but also the capabilities of the car batteries. Nonetheless, the EVs, either with or without V2G option, have a large impact on the electricity demand (and for countries with a large CHP share, also on the heating sector).

An important factor is the share the EVs would demand as part of the whole electricity demands. In ESA3, if EVs are to cover 25% of the driving demand (of total distances covered; not energy demanded), it represents 3-10% of the electricity demand in Austria, Denmark and Norway. As it depends on the registered transport needs in each of the countries' reference models, 25% are of very different magnitudes. Therefore, the electricity demand for 25% of transport to be covered from EVs in Austria, Denmark and Norway is 6.9, 3.6 and 4.0 TWh/year from the total electricity productions of 68.7, 40.3 and 141.3 TWh/year respectively.

When it comes to the importance of duration and ways of charging the cars, two main trends are analysed: firstly, constant dump charge and secondly, smart charge depending on the driving demand and when it is optimal to charge – taking the energy system into consideration – hence smart for the energy system and for the technology required. The difference of the two trends is shown with Figure 4.6, where constant charging and smart charging based on driving demand profiles are illustrated. The blue bars are hourly charging demands, while the red bars represent the hourly driving demand of two days in January. The latter one is resulting in changing charging profiles for every day under the smart charging simulation.

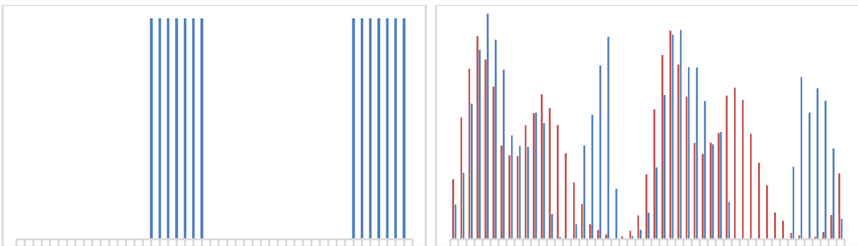

Figure 4.6: 48 hours of two charging profiles (in blue). Left: constant/dump from 17-24:00. Right: smart/ depending on the driving demand (in red)

The dump charging is often considered to take place during the evening/night time, starting from after work hours, as people return home and are able to plug the cars in for charging. Depending on the charger and car, this process could take a few hours and up to the whole night. In contrast, some studies may suggest that EVs could be charged during the daytime, when they are connected to a charger during the working hours. No matter which one is studied, the important factor is the fact that it takes place in a dump way, meaning no flexibility in the quantity of electricity required. The second option of charging takes place whenever it makes sense from the energy system's point of view and when there is a driving demand. This option takes several more factors into account, namely:

- Typical weekday, weekend driving demands
    - Whenever there is no driving demand, a certain share of cars can charge. Likewise, when the driving demand is high, the charging demand is low.

- Max. share of cars during peak demand 20%
- 70% of parked cars grid connected
- 90% charging efficiency

For this, the EVs need to be defined in more detail, including charging and battery capacities. In this ESA, the typical values of a Nissan Leaf are used: Capacity of connection is 6 kW per car and battery storage capacity is 21.3 kWh per car, resulting in total added capacities of 51, 27 and 29 GWh for Austria, Denmark and Norway respectively.

In addition to the smart charge option comes the V2G ability. For this, an additional discharge connection capacity 6 kW per car is added at a 90% discharge efficiency.

While the dump charge can take place in various ways, the one from 17-24:00 is considered the most likely and is therefore put in contrast to smart V2G charging. This can be seen in Figure 4.7, while Figure 4.8 present the various charging times and options for the Danish case as an example. As can be seen in Figure 4.8, the differences are minor and therefore, the focus is set on the two main contrasting options in Figure 4.7. The results are as follows:

The references have very few EVs, so compared to that, CO_2 is always reduced (0.6-3.7% for dump charged EVs and up to additional 1.7% reduction for smart/V2G)

From diesel to EVs: more electricity demand and increased PP, CHP reduction and therefore higher boiler share

Dump charge overnight adds in average the lowest demand on top of the electricity demand profile (charging is spread over 14h), this additional load is twice as much when charging time is shortened to midnight (7h) – daytime charging is over 8h, but adds up to daily demands, which puts strain on the already higher daytime demands (Figure 4.4)

- 8h daytime charging better than 7h night time charging but worse than 14h night charging for Austria and Denmark, but in Norway evening charging is the best, closely followed by daytime charging
- Smart charge not so good in Austria, good in Denmark and Norway
- V2G: Best results for Austria; Denmark only minor and Norway only smallest improvement

Austria

- Lowest CO_2 and fuel reductions (-1%)
- Electricity import increases for dump charge
- Hydro power production increases, raises the RES share of electr. demand from 54 to 58%
  - V2G balancing only used 0.03 TWh
  - Austria has some fixed export, fixed PP production, large electricity storage already (dammed hydro/storage: 4365/4793 MW capacity)

Denmark

- CO_2 and fuel reductions of up to 5.4 and 4%
- Electricity export reduced, V2G balancing utilized 0.51 TWh
  - Denmark has no hydro storage, so it can use the additional EV storage
- CHP operation increases with increasing electricity demand, therefore boiler heat production reduces

Norway

- CO_2 and fuel reductions of 3%
- Electricity export reduced by 35%, V2G balancing utilized 0.29 TWh
- No large impacts on the heating sector (no major CHP)
  - Norway has some storage in combination with the dammed hydro (1350/30020 MW capacity)

In Figure 4.7, only the two scenarios of dump charge (17-24:00) and V2G is presented, as explained above, due to the high similarity between the various dump charging alternatives and the two smart charging variations. The details of these, however, can be viewed in Figure 4.8 with the exemplary Danish reference system and all results from the dump and smart charge variations.

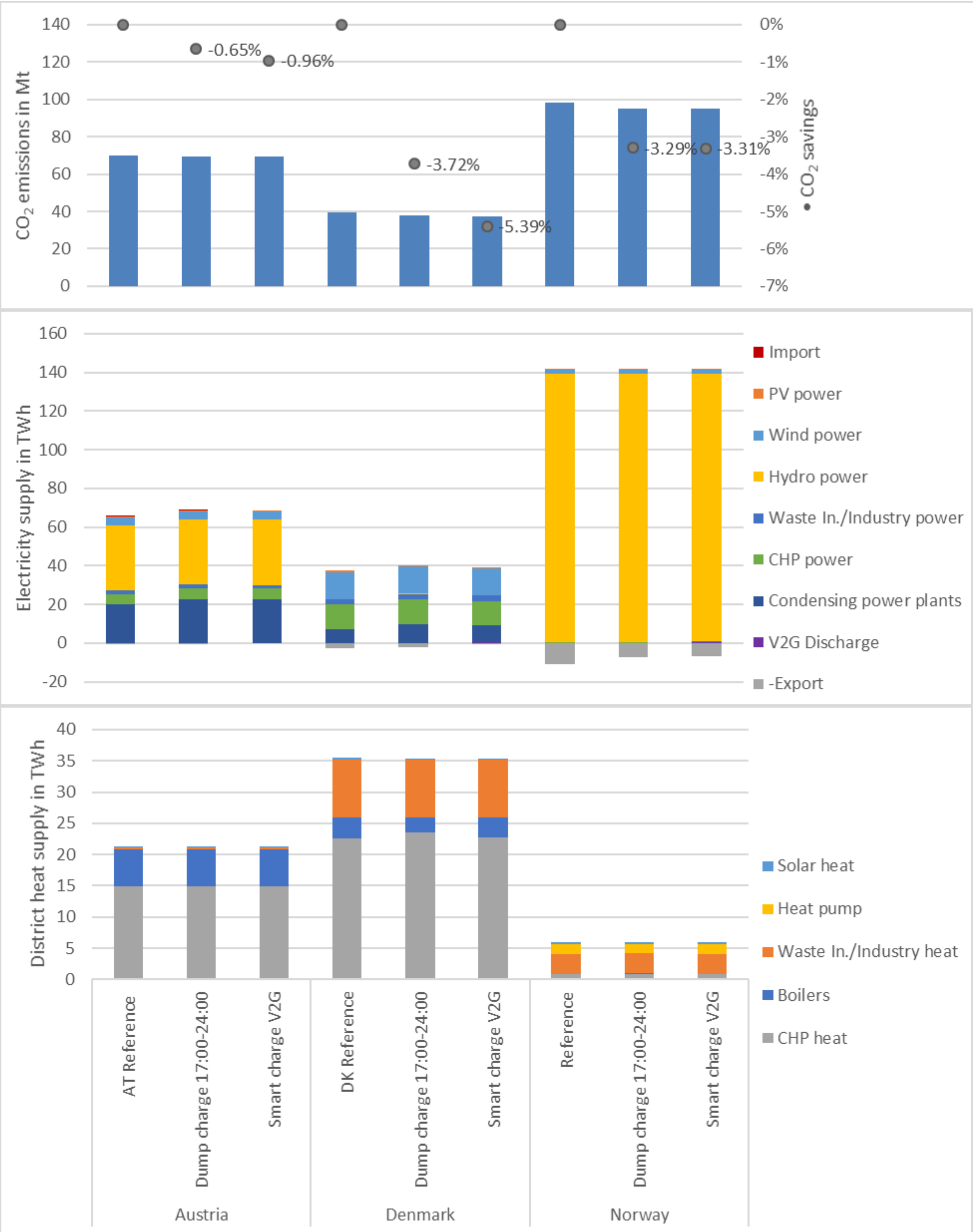

Figure 4.7: Electricity and DH supply by technology for EV scenarios, incl. CO_2 emissions

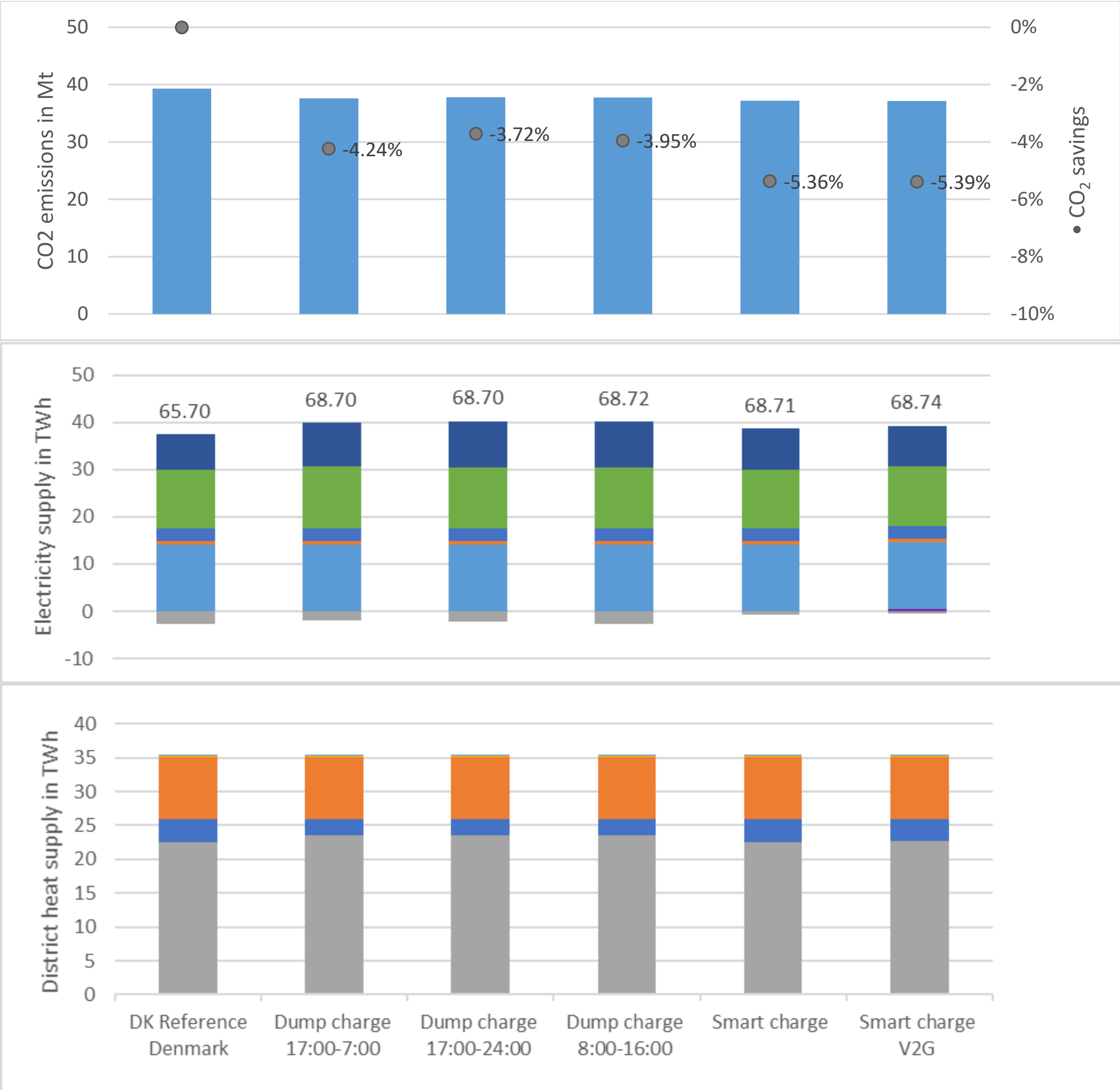

Figure 4.8: Energy supply by technology for EV scenarios in Denmark, incl. CO2 emissions (supplementary)

As can be seen in Figure 4.8, the three dump charge approaches result in similar values for CO_2, electricity and heat supply, as well as the two smart charge approaches. The first approaches already show a big increase in electricity demand, which effects the electricity production, and in the case of Denmark, also strongly the heating production. A main tendency from the second one is the advantages of V2G besides only focusing on the charging aspect. If the option exists, the V2G can enhance the results from smart charging, if this should be considered.

5 Discussion and conclusion

WP4 of the MATCH project focuses on the ESAs of the various suggested study cases and approaches from WP2. The results are presented in three areas of investigation: *ESA 1 – CHP and/or HP replacing individual heating with PV support*, *ESA 2 – Electricity demand time shift based on DSM* and *ESA 3 – EVs and charging variations: dump/smart/V2G.*

The ESAs show the dynamic relations of not only the different smart grid solutions, but also the impacts on the electricity sector and the heat sector, as seen from the national perspective. For this, the case studies are rescaled and extended to the national scale of Austria, Denmark and Norway.

The visualization of the system-related consequences of combining different solutions did not show clear tendencies of advantages and disadvantages of the different approaches, but rather the variation they can have in different contexts.

Generally, all approaches have the tendency to reduce CO_2 emissions and fossil fuel consumption, but not all improve the electricity exchange significantly, which is also an important indicator for a successful technology. Being able to supply a country locally without depending on other countries increases security of supply and stability in the local market.

While the energy systems analyses do not focus on the market implications – i.e. how the units will operate in an electricity market – the general costs for the systems also have a positive tendency, because for example fuels can be saved. This is added to the detailed results of each country in the Appendix, but should be regarded with some caution, as the simulation and its results (also the costs) are performed using a technical simulation strategy where the aim is to simulate the best load-following capability and most energy efficient operation of the energy system. For proper market simulations, actual hourly future prices would need to be known. However, the technical simulation presented in this paper give the correct indication of the future energy system's tendency nonetheless. This can be assumed since high shares of RES would also be reflected in generally lower electricity costs and hence economic incentives to use electricity on heat pumps and other units or use heat from a heat storage – and incentives not to produce on e.g. CHP units; just as the system also would operate in a technical simulation.

Regardless of the initiatives, due to a general electrification of the society, more electricity production capacity is required, preferable based on RES. With the current energy systems, the increased demands would otherwise lead to increased fuel consumption in the currently fossil-fueled production units, like old condensing-mode power plants. This is the situation for the reference systems of Austria and Denmark, while the impact on Norway would be the possible exhaustion of the hydropower production. While the renewable electricity production in Norway is currently above the local demands, the ESA3 reduces the excess production by 45% already, indicating a limit in the increase of electricity consumption without other improvements in the electricity sector.

Overall, the ESAs give an indication to regard seemingly good technologies and approaches more carefully. While HPs and EVs are considered in a positive light, they can have negative consequences on certain energy systems or constellations, shown in ESA1 and ESA3. In addition, the DSM idea of aiming at peak reductions should be well considered, as presented in ESA2. Energy planners and decision makers need to take hourly demands, seasonal changes and the possible consequences of certain DSM approaches into account. The complexity of different technologies and approaches in different energy systems is shown with this MATCH WP4 by evaluating the same ideas in different contexts. This directs to the importance of carefully designing and evaluating markets, actors and technologies.

In general, however it may be concluded: that the CHP DH combination has a role to play particularly in the Austrian energy systems; that HPs are well-suited in the Norwegian context and that EVs must be well integrated using smart charging and possibly also V2G facilities – as proven valuable for Denmark – to minimize negative impacts and maximize positive impacts on the electricity system.

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Appendix

Austria EnergyPLAN model Annual modelled values	Reference	ESA1 10%CHP/HP +25%PV	ESA1 10%HP +25%PV	ESA2 -5% DSM in 17.00-21.00	ESA2 -10% DSM in 17.00-21.00	ESA3 Dump charge 17:00-24:00	ESA3 Smart charge V2G
CO2 emissions in Mt	70.026	69.107	69.982	69.999	69.979	69.57	69.355
RES share of PES	20.5	20.8	20.6	20.5	20.5	20.6	20.8
RES share electr. demand	53.9%	54%	53%	54%	54%	52%	58%
Fuel consumption	**301.49**	296.54	299.91	301.37	301.28	299.45	298.71
Electricity production	**65.71**	**65.85**	**67.42**	**65.71**	**65.72**	**68.66**	**68.74**
Heat demand	**73.09**	73.05	73.05	73.04	73.04	73.04	73.04
DH share	29%	36%	36%	29%	29%	29%	29%
Import	0.01	0	0.01	0	0	0.06	0
Export	0.02	0.09	0.01	0.01	0.01	0.02	0
Electricity production & demand (TWh)							
RES1 (Wind onshore)	4.11	4.11	4.11	4.11	4.11	4.11	4.11
RES2 (Wind offshore)	0	0.21	0.21	0	0	0	0
RES3 (PV)	0.83	0.83	0.83	0.83	0.83	0.83	0.83
RES4 (River Hydro)	11.6	11.6	11.6	11.6	11.6	11.6	11.6
Dammed Hydro	21.87	21.85	21.89	21.9	21.93	21.88	22.23
Waste inc./Industry	1.82	1.82	1.82	1.82	1.82	1.82	1.82
CHP power	5.57	7.46	5.59	5.59	5.6	5.57	5.54
Condensing PPs	19.91	17.97	21.37	19.86	19.83	22.85	22.58
V2G							0.03
Electricity demand (direct)	55.08	55.08	55.08	55.08	55.08	55.08	55.08
Electricity for transportation/flexible	7.04	7.04	7.04	7.04	7.04	10.05	3.13
Electricity for heating DH HP	0	0.06	1.73	0	0	0	0
Electricity for heating HH HP	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Electricity for heating HH EB	8.33	8.33	8.33	8.33	8.33	8.33	8.33
Electricity for cooling	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Heat production & demand (TWh)							
DH Solar heat	0.08	0.08	0.08	0.08	0.08	0.08	0.08
DH Waste heat	0.44	0.44	0.44	0.44	0.44	0.44	0.44
DH CHP heat	14.92	19.97	14.97	14.95	14.98	14.92	14.84
DH Heat pump	0.01	0.19	5.19	0.01	0.01	0.01	0.01
DH Boilers	5.82	5.77	5.76	5.78	5.76	5.82	5.9
DH Electr. Boiler	0	0.01	0.01	0.01	0.01	0.01	0.01
Balance heat	0	0	0	0	0	0	0
Indv. Heat pump	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Indv. Electric boiler	8.33	8.33	8.33	8.33	8.33	8.33	8.33
Indv. Fuel Boiler	42.37	37.2	37.2	42.37	42.37	42.37	42.37
Indv. Solar heat	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Heat demand DH	*21.27*	26.40	26.40	21.22	21.22	21.22	21.22
Heat demand HH	51.82	46.65	46.65	51.82	51.82	51.82	51.82
Fuels (TWh)							
Coal consumption	50.87	51.3	52.66	50.83	50.8	54.42	54.07
Oil consumption	119.3	119.71	119.38	119.3	119.3	109.44	109.42
NGas consumption	100.77	95.01	97.36	100.72	100.67	105.04	104.63
Biomass consumption	30.55	30.52	30.51	30.52	30.51	30.55	30.59
Annual costs (k€)							
Fuels excl. Gas	6795	6760	6753	6794	6793	6341	6338
Gas	2510	2367	2426	2509	2508	2617	2607
Marginal operation costs	94	94	99	94	94	102	102
Electricity exchange Import	0	0	0	0	0	0	0
Electricity exchange Export	0	0	0	0	0	0	0
CO2 costs	1064	1050	1064	1064	1064	1057	1054
Fixed operations costs	19	18	18	19	19	19	19
Investments	3827	3743	3707	3827	3827	3827	3827
Total	14304	14027	14061	14301	14299	13957	13940

Denmark EnergyPLAN model Annual modelled values	Reference	ESA1 10%CHP/ HP +25%PV	10%HP +25%PV	ESA2 -5% DSM in 17.00-21.00	-10% DSM in 17.00-21.00	ESA3 Dump charge 17:00-24:00	Smart charge V2G
CO2 emissions in Mt	39.291	38.761	38.807	39.263	39.243	37.831	37.174
RES share of PES	31.4	31.9	31.9	31.4	31.4	33	33.1
RES share electr. demand	42.3%	42%	42%	42%	42%	39%	43%
Fuel consumption	192.76	190.58	190.69	192.65	192.57	187.89	184.92
Electricity production	37.46	37.84	37.85	37.40	37.35	40.27	39.30
Heat demand	56.42	56.43	56.43	56.42	56.42	56.42	56.42
DH share	63%	67%	67%	63%	63%	63%	63%
Import	0	0	0	0	0	0	0
Export	2.55	2.42	2.42	2.53	2.49	2.2	0.57
Electricity production & demand (TWh)							
RES1 (Wind onshore)	9.31	9.31	9.31	9.31	9.31	9.31	9.31
RES2 (Wind offshore)	4.84	4.84	4.84	4.84	4.84	4.84	4.84
RES3 (PV)	0.6	0.76	0.76	0.6	0.6	0.6	0.6
RES4 (River Hydro)	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Dammed Hydro	0	0	0	0	0	0	0
Waste inc./Industry	2.8	2.8	2.8	2.8	2.8	2.8	2.8
CHP power	12.45	13	12.88	12.44	12.43	12.97	12.49
Condensing PPs	7.44	7.11	7.24	7.39	7.35	9.73	8.73
V2G	0	0	0	0	0	0	0.51
Electricity demand (direct)	31.27	31.27	31.27	31.27	31.27	31.27	31.27
Electricity for transportation/flexible	0.4	0.4	0.4	0.4	0.4	3.63	0
Electricity for heating DH HP	0.02	0.56	0.57	0.02	0.02	0.01	0.01
Electricity for heating HH HP	0.77	0.77	0.77	0.77	0.77	0.77	0.77
Electricity for heating HH EB	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Electricity for cooling	1.67	1.67	1.67	1.67	1.67	1.67	1.67
Heat production & demand (TWh)							
DH Solar heat	0.23	0.23	0.23	0.23	0.23	0.23	0.23
DH Waste heat	9.18	9.18	9.18	9.18	9.18	9.18	9.18
DH CHP heat	22.58	23.63	23.41	22.58	22.58	23.59	22.67
DH Heat pump	0.06	2.12	2.16	0.06	0.06	0.05	0.05
DH Boilers	3.38	2.38	2.57	3.4	3.39	2.38	3.3
DH Electr. Boiler	0	0	0	0	0	0	0
Balance heat	0.01	0.01	0.01	0.01	0.01	0.01	0
Indv. Heat pump	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Indv. Electric boiler	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Indv. Fuel Boiler	17.8	15.69	15.69	17.8	17.8	17.8	17.8
Indv. Solar heat	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Heat demand DH	35.44	37.55	37.55	35.44	35.44	35.44	35.44
Heat demand HH	20.98	18.88	18.88	20.98	20.98	20.98	20.98
Fuels (TWh)							
Coal consumption	28.76	28.39	28.56	28.7	28.65	32.1	30.63
Oil consumption	77.33	77.32	77.33	77.33	77.33	66.71	66.57
NGas consumption	36.48	34.54	34.48	36.46	36.45	37.19	36.71
Biomass consumption	50.19	50.33	50.32	50.16	50.14	51.89	51.01
Annual costs (k€)							
Fuels excl. Gas	4955	4923	4924	4953	4952	4456	4418
Gas	795	752	751	794	794	810	800
Marginal operation costs	33	32	33	33	32	39	36
Electricity exchange Import	0	0	0	0	0	0	0
Electricity exchange Export	-33	-31	-31	-32	-32	-28	-7
CO2 costs	299	295	296	299	299	288	283
Fixed operations costs	4170	4185	4171	4170	4170	4170	4170
Investments	8549	8558	8536	8549	8549	8549	8549
Total	18767	18715	18679	18765	18764	18285	18249

Norway EnergyPLAN model Annual modelled values	Reference	ESA1		ESA2		ESA3	
		10%CHP/ HP +25%PV	10%HP +25%PV	-5% DSM in 17.00-21.00	-10% DSM in 17.00-21.00	Dump charge 17:00-24:00	Smart charge V2G
CO2 emissions in Mt	98.337	98.221	97.03	98.345	98.347	95.104	95.08
RES share of PES	28.7	28.7	29	28.7	28.7	29.3	29.4
RES share electr. demand	107.7%	108%	107%	108%	108%	105%	108%
Fuel consumption	398.59	398.78	392.97	398.62	398.64	386.41	386.29
Electricity production	141.23	143.07	141.25	141.24	141.24	141.26	141.52
Heat demand	60.06	60.07	60.07	60.06	60.06	60.06	60.06
DH share	9%	18%	18%	9%	9%	9%	9%
Import	0	0	0	0	0	0	0
Export	10.75	12.61	9.63	10.78	10.79	7.14	6.99
Electricity production & demand (TWh)							
RES1 (Wind onshore)	2.12	2.12	2.12	2.12	2.12	2.12	2.12
RES2 (Wind offshore)	0	0	0	0	0	0	0
RES3 (PV)	0.01	0.01	0.01	0.01	0.01	0.01	0.01
RES4 (River Hydro)	4.88	4.88	4.88	4.88	4.88	4.88	4.88
Dammed Hydro	133.57	133.57	133.57	133.57	133.57	133.57	133.57
Waste inc./Industry	0.35	0.35	0.35	0.35	0.35	0.35	0.35
CHP power	0.3	2.14	0.32	0.31	0.31	0.33	0.3
Condensing PPs	0	0	0	0	0	0	0
V2G	0	0	0	0	0	0	0.29
Electricity demand (direct)	96.91	96.91	96.91	96.91	96.91	96.91	96.91
Electricity for transportation/flexible	0.27	0.27	0.27	0.27	0.27	3.96	0
Electricity for heating DH HP	1.19	1.17	2.33	1.18	1.17	1.14	1.19
Electricity for heating HH HP	6.52	6.52	6.52	6.52	6.52	6.52	6.52
Electricity for heating HH EB	24.59	24.59	24.59	24.59	24.59	24.59	24.59
Electricity for cooling	1	1	1	1	1	1	1
Heat production & demand (TWh)							
DH Solar heat	0	0	0	0	0	0	0
DH Waste heat	3.25	3.25	3.25	3.25	3.25	3.25	3.25
DH CHP heat	0.83	4.28	0.87	0.85	0.86	0.9	0.82
DH Heat pump	1.6	3.44	6.84	1.58	1.57	1.53	1.6
DH Boilers	0.03	0	0	0.03	0.03	0.03	0.03
DH Electr. Boiler	0	0	0	0	0	0	0
Balance heat	-0.2	0	0	-0.2	-0.2	-0.2	-0.2
Indv. Heat pump	15	15	15	15	15	15	15
Indv. Electric boiler	24.59	24.59	24.59	24.59	24.59	24.59	24.59
Indv. Fuel Boiler	14.94	9.5	9.5	14.94	14.94	14.94	14.94
Indv. Solar heat	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Heat demand DH	5.51	10.97	10.97	5.51	5.51	5.51	5.51
Heat demand HH	54.55	49.1	49.1	54.55	54.55	54.55	54.55
Fuels (TWh)							
Coal consumption	16.32	16.32	16.32	16.32	16.32	16.32	16.32
Oil consumption	278.7	276.05	276.05	278.7	278.7	266.41	266.41
NGas consumption	89.49	92.36	86.55	89.53	89.54	89.6	89.48
Biomass consumption	14.08	14.05	14.05	14.07	14.08	14.08	14.08
Annual costs (k€)							
Fuels excl. Gas	113978	112203	111985	113978	113979	106013	106010
Gas	23473	24226	22701	23483	23486	23501	23471
Marginal operation costs	510	401	360	510	510	510	510
Electricity exchange Import	0	0	0	0	0	0	0
Electricity exchange Export	-1322	-1536	-1173	-1325	-1335	-859	-801
CO2 costs	5900	5893	5822	5901	5901	5706	5705
Fixed operations costs	5258	8719	5287	5258	5258	5258	5258
Investments	16970	26194	17744	16970	16970	16970	16970
Total	164768	176100	162726	164775	164769	157100	157123